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Interpretation of the polarization transfer measurement in the (p, p′) reaction on ^{208}Pb

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The results of the experiment of Carey *et al.* on the polarization transfer in the (p, p′) reaction on ^{208}Pb are discussed with respect to their relevance for the absence or presence of collective effects in the nuclear spin-isospin response.

The collective behavior of the spin-isospin nuclear response has recently been extensively investigated.[1] The pion exchange force plays here a crucial role: in particular, it provides an attraction in the spin longitudinal channel, whereas, in a nuclear matter framework, it cannot be operative in the transverse one. As a consequence a striking contrast between the two responses is expected to take place at moderate momenta.[2,3]

In order to test these predictions Carey *et al.*[4] have carried out a remarkable experiment of inclusive polarized proton scattering. By measuring the polarization transfer they have been able to identify, for the first time, both the spin longitudinal (R_L) and the spin transverse (R_T) responses providing the ratio $R_L(\omega)/R_T(\omega)$ at the fixed momentum transfer $q=1.75\ \text{fm}^{-1}$. This ratio turns out to be remarkably close to one over a wide range of energies (30–100 MeV) and no sign of contrast shows up in their results.

Since collectivity naturally leads to a contrast, which, however, has not been observed, the first natural interpretation of this experiment would exclude collective effects. The spin-isospin nuclear responses should, therefore, be interpreted in terms of a pure Hartree-Fock theory.

However, before sticking to this conclusion, we believe that several points should be cleared up.

To start with Carey *et al.*[4] point out that in their experiment the isoscalar ($\tau=0$) response appreciably contributes, particularly in the transverse channel. On the basis of the Arndt nucleon-nucleon phase shifts, they claim to measure, in fact, the following combinations:

$$\tilde{R}_L(q,\omega)=\frac{1}{4.6}[R_L^{\tau=0}(q,\omega)+3.6R_L^{\tau=1}(q,\omega)] \ , \tag{1}$$

$$\tilde{R}_T(q,\omega)=\frac{1}{2}[R_T^{\tau=0}(q,\omega)+R_T^{\tau=1}(q,\omega)] \ . \tag{2}$$

Now the presence of the isoscalar contribution considerably brings the ratio

$$\chi=\frac{\tilde{R}_L}{\tilde{R}_T} \tag{3}$$

down toward unity. Indeed the enhancement expected in the $\tau=1$ channel arises from the increase of $R_L^{\tau=1}$, but mostly from the quenching of $R_T^{\tau=1}$, both effects brought in by collectivity. Concerning the isoscalar response, it is essentially of single particle character owing to the weakness of the corresponding particle-hole force. Therefore, its presence, strongly felt in the denominator of (3), automatically washes out to a large extent the signature of collectivity, particularly in the transverse channel.

A second point refers to the peripheral nature of the proton-nucleus interaction. In the experiment of Carey *et al.*[4] it is essentially the surface of the nucleus which is probed. As a consequence, the interaction develops in a region where the density, much lower than the central value, is furthermore rapidly varying. Accordingly, collective effects are less pronounced as in a dilute system. Moreover, a certain coupling between the transverse and longitudinal interactions should occur. This effect obviously cannot be incorporated in our present nuclear matter treatment.

Nevertheless, to get at least a first orientation on the effects associated with the lowering of the density, we have combined the nuclear matter responses at the densities $0.3\rho_0$, $0.5\rho_0$, $0.7\rho_0$, and $0.9\rho_0$ ($\rho_0=0.17$ nucleons/fm^3) with the respective weighting factors 0.25, 0.25, 0.3, and 0.2, according to the indications of the intranuclear cascade estimate of Ref. 4.

The results of our calculations are displayed in Fig. 1, where χ is shown for various values of the Landau-Migdal parameter g'. Our theoretical curves turn out to be significantly lower than those reported by Carey *et al.*[4] reflecting both the peripheral character of the proton-nucleus interaction and the presence of the isoscalar contribution. The latter, in addition, makes χ sensitive to the actual value of g', as illustrated in Fig. 1.

Note that for $g'=1$ the theoretical curve is frequency independent, as it happens for the experiment. However, our description of deep inelastic electron scattering favors a lower value for g', namely, 0.7–0.8. For such values the disagreement between our nuclear matter treatment and the experimental data is still significant (although no longer as striking as pretended by Carey *et al.*[4]).

The remaining discrepancy might be due to finite size effects. One should not forget that the contrast between the *isovector* spin responses arises from the decoupling between pion- and rho-like excitations, which is total only in infinite nuclear matter.[2,3] In a finite system, instead, pion and rho are mixed, as previously mentioned, in the surface region, the one mainly explored by the experiment of Carey *et al.*[4] This mixing is likely to further attenuate the contrast between the two responses, entailing an additional reduction of χ. To account for it, a proper treatment of the surface response, like the one of Esbensen and Bertsch,[5] is needed.

In view of these considerations we think that the question

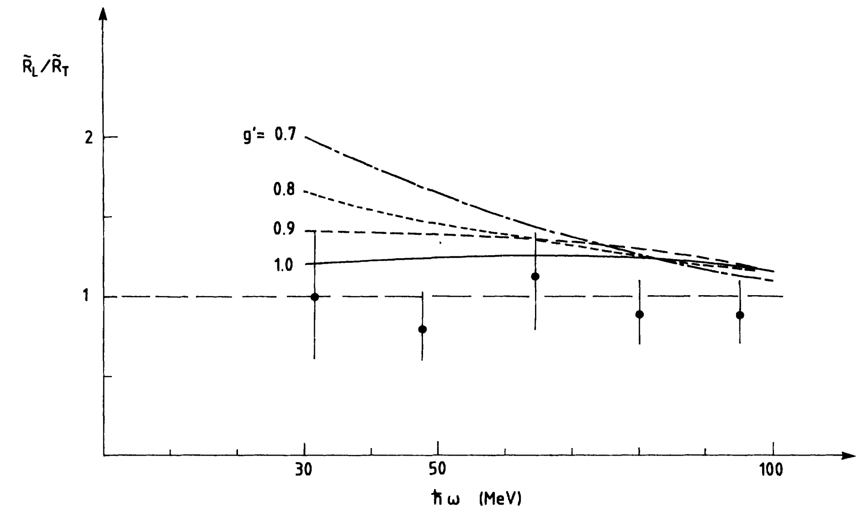

FIG. 1. Ratio χ [Eq. (3)] between the spin longitudinal and spin transverse responses, calculated in the nuclear matter framework and density averaged for different values of the Landau-Migdal parameter g'. The experimental points are taken from Ref. 4.

of the collective nature of the spin-isospin nuclear responses is still open. Actually we believe that the electron scattering experiments, which instead probe the inner region of the nucleus, support the collective interpretation of the isovector spin transverse response. Indeed, as shown in Fig. 2, we obtain a good account of the Saclay data[6] at $q=1.67$ fm^{-1} (close to the one of Carey *et al.*) by adding the 2p-2h (two particles-two holes) contribution to a collective 1p-1h response.[7] Whether a similar agreement could be reached without collectivity in the 1p-1h sector remains to be seen.

We will implement this viewpoint by considering the sum rule S_0 in the transverse channel. We have extracted the experimental values of S_0 from the Saclay (e,e′) data integrated up to the maximum energy below the Δ region. The experimental points are displayed in Fig. 3 together with the free Fermi gas value which, we recall, is insensitive to the action of an Hartree-Fock field.[8] The data are close to the free sum rule. However, it would be deceptive to infer that the nuclear response is of single particle nature.

In fact such an interpretation would leave no room for the 2p-2h contribution. The latter, as illustrated in Fig. 2, play a dominant role in the high energy domain and should contribute substantially to S_0 (in our evaluation $\sim 30\%$ of the total sum, see Fig. 3). Accordingly, a proper account of

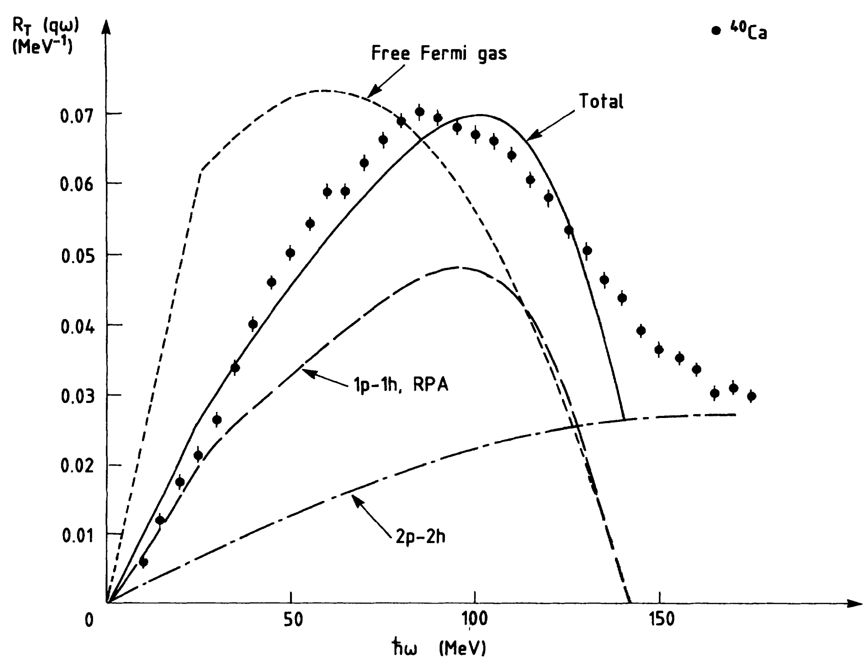

FIG. 2. Separated transverse magnetic response in ^{40}Ca at $q=330$ MeV/c as a function of $\hbar\omega$. The experimental points are taken from Ref. 6. The 2p-2h, the RPA 1p-1h (with $g'=0.7$) and the total responses are shown, together with the free Fermi gas one ($k_F=1.2$ fm^{-1}).

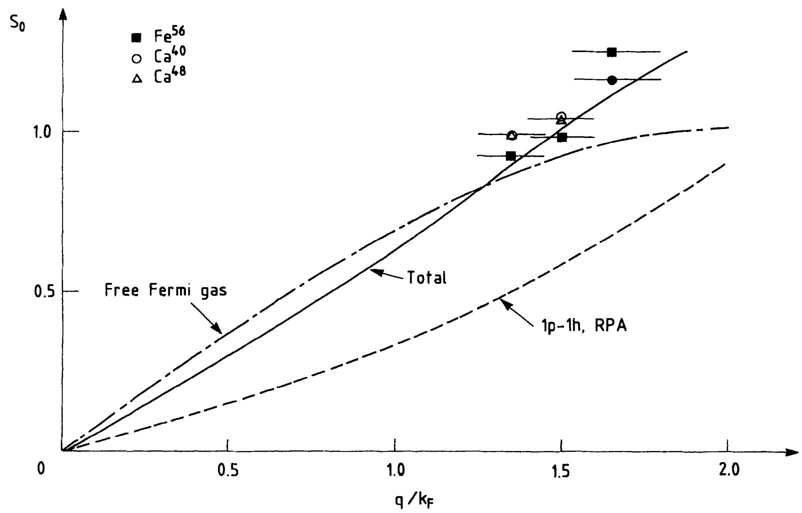

FIG. 3. Transverse sum rule S_0 as a function of q/k_F. The free Fermi gas value, the RPA 1p-1h (with $g' = 0.7$) sum rule and the total one (including the 2p-2h contribution) are shown. The experimental points have been extracted with the procedure explained in the text from Ref. 6. The error bars on the abscissa reflect the uncertainty in the averaged Fermi momentum for the considered nuclei.

the transverse S_0 requires a certain amount of quenching in the 1p-1h response, brought in by random-phase approximation (RPA) correlations.

Thus we favor an interpretation of the sum rule based on 2p-2h excitations plus a collective (quenched) 1p-1h contribution. This is perfectly in line with the recognized fact that strength is created in the spin-isospin channel by the tensor correlations.

In the spin longitudinal channel, the one relevant for the pionic interpretation of the Europeen Muon Collaboration (EMC) effect,[9] we expect a similar, thus *sizable,* contribution from the 2p-2h excitations. On the other hand, here the presence of the pion counteracts the short range repulsion, thus preventing a quenching of collective origin of the 1p-1h sum rule. One is naturally led, therefore, to predict some enhancement of the spin longitudinal sum rule, the minimum one being associated with the 2p-2h contribution. This will be the case when the 1p-1h longitudinal response coincides with the Hartree-Fock one.

This enhancement of the spin longitudinal response in the low energy domain can be equivalently expressed in terms of an increased number of low energy pions per nucleon in the nucleus with respect to the free case, in agreement with the findings of Friman *et al.*[10] This seems rather natural, since the nuclear binding, after all, stems largely from Van der Waals–type forces originated by the exchange of two pions (σ mesons). In addition, a strong enhancement of the spin longitudinal response arises, at higher energies, from the collective pionic branch.[11]

In summary, the experiment of Carey *et al.*[4] raises interesting questions concerning the description of the surface spin-isospin response. The relation of the latter with the volume response is still unclear and requires additional investigations. Meanwhile, any conclusion about the nature of the *volume* spin-isospin response is, in our opinion, premature.

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